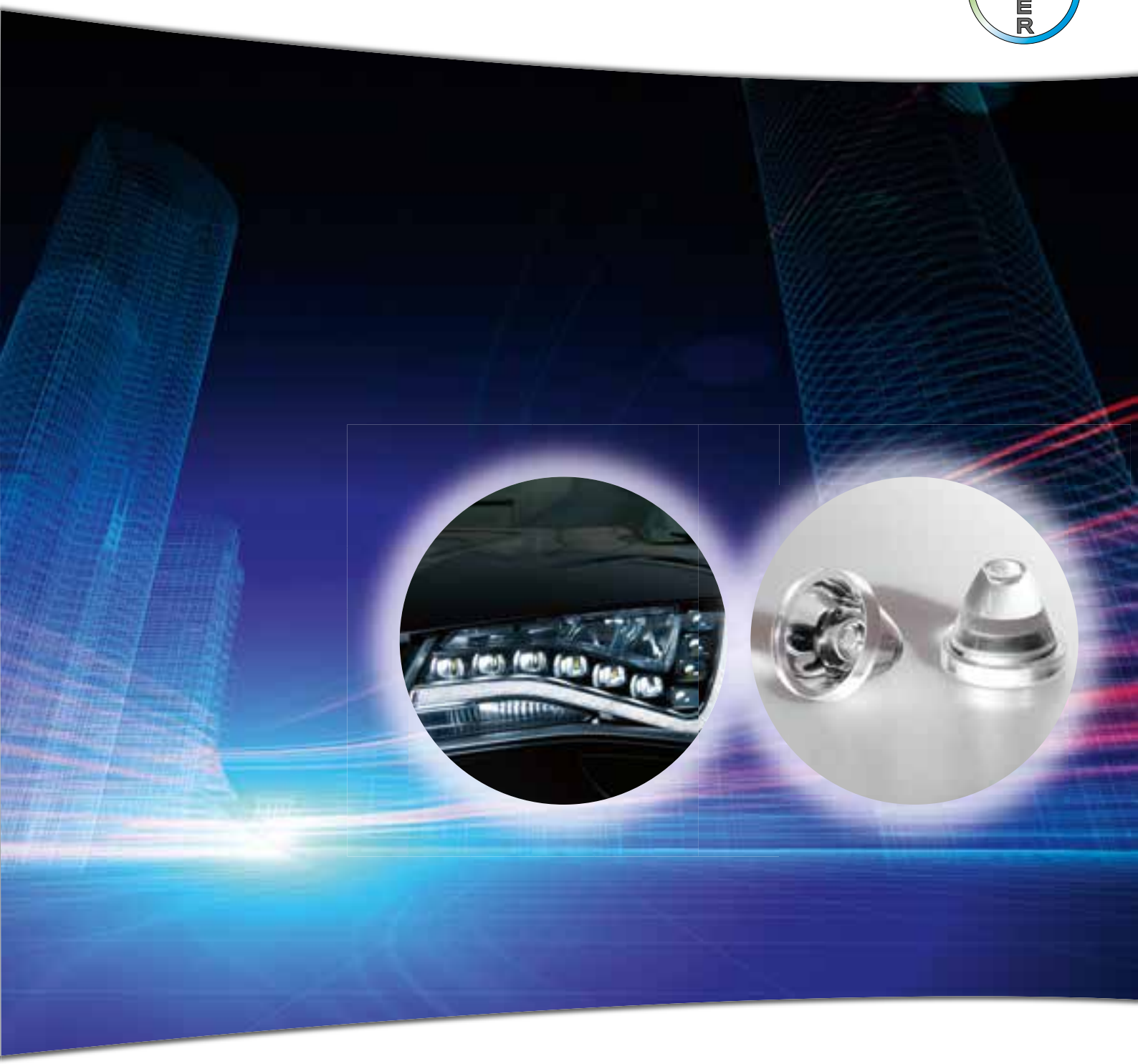


Optical properties of Makrolon® and Apec® for non-imaging optics

MAKROLON®

APEC®

Content

1 Introduction

Makrolon® and Apec® polycarbonates from Bayer MaterialScience are characterized by a combination of crystal clear transparency, high heat resistance, high strength and good flame retardant properties.
This brochure mainly describes the optical properties of Makrolon® and Apec®, and how they are affected by temperature and UV light. However, a brochure of this kind can only cover a limited selection of the diverse sets of requirements.
In its polycarbonates portfolio, Bayer MaterialScience distinguishes optical Makrolon® grades and other specialty grades, such as the high-temperature polycarbonate Apec®, from the standard Makrolon® grades. This brochure focuses on the optical properties of the optical Makrolon® and Apec® grades. Please refer to the separate brochures for information on the Makrolon® LQ product line for the corrective eyewear market, or Makrolon® for extrusion, food contact and medical technology applications.

All values are typical, not specified values.

A | Nomenclature

The following system of nomenclature is used for most Makrolon® and Apec® grades:

The designation of Makrolon® and Apec® sales products are based on a 4-digit, self-explanatory nomenclature.

Makrolon® LED 22 4 5

The first two digits denote the viscosity:
- 22 low viscosity
- 24 low viscosity
- 26 medium viscosity
- 28 medium viscosity
- 31 high viscosity

Digit 3 differentiates between standard grades and special grades:
- 0 standard grade
- 1 or 4 special grade, often specified by a prefix, such as OD, LED, AL or LQ

The fourth digit denotes additive package:
- 5 easy release
- 7 easy release, UV-stabilized

Apec® 20 9 7

The first two digits denote the heat resistance:
- 16 Vicat approx. 160 °C
- 17 Vicat approx. 170 °C
- 18 Vicat approx. 185 °C
- 20 Vicat approx. 203 °C

Digits 3 and 4 describe the grade:
- 95 easy-flowing, easy release
- 97 easy-flowing, UV-stabilized, easy release
- 03 grade with elevated viscosity, UV-stabilized

The fourth digit denotes additive package:
- 5 easy release
- 7 easy release, UV-stabilized

B | Color designation

The material designation is followed by a 6-digit color code. The first two digits indicate the main color, the other four digits serve to distinguish between different shades. The designation 000000 refers to a natural shade with no added color.
The following sections describe Makrolon®. Apec® is described in the last section.

Table 1: Color designation of Makrolon® and Apec®

	Opaque colors	Transparent colors	Translucent colors
White	01	–	02 (translucent white)
Yellow	10	15	12
Orange	20	25	22
Red	30	35	32
Violet	40	45	42
Blue	50	55	52
Green	60	65	62
Grey	70	75	72
Brown	80	85	82
Black	90	–	–

2 Clear, transparent Makrolon® grades

Bayer MaterialScience sells standard grades with and without UV protection and in various viscosities. The MVR ranges from 36 cm^3/10 min for low-viscosity grades (Makrolon® 2205 550115 and Makrolon® 2207 550115) to 10 cm^3/10 min for injection molding grades of medium viscosity (Makrolon® 2805 550115 and Makrolon® 2807 550115).
For more information on high-viscosity grades, refer to the separate brochure on extrusion (MS00045300_Makrolon® ET–Resins for Extrusion and Thermoforming [2009-10]).

- Makrolon® OD2015 was developed specifically for the manufacture of optical data storage media. It is a high-flow grade available only in a natural color.
- Makrolon® LED2045 and LED2245 are both optimized for applications requiring high transmission for long optical paths (e.g. optical fibers) combined with high resistance to intense LED light. Availability of the two grades varies by region. They are both low-viscosity grades. Makrolon LED2045 is available in natural color 000000 only. Makrolon LED2245 is available in natural color 000000 and icecolor 550207.
- Makrolon® AL2447 and Makrolon® AL2647 are low-to-medium-viscosity specialty grades for headlamp covers. They are offered in the color 550396 (551070 NAFTA only). These grades display a slightly bluish tint that is very consistent from batch to batch. Together with various scratch-resistant coatings, they are approved under ECE and AMECA for automotive headlamps.

Table 2: Basic properties of selected clear Makrolon® grades

	General purpose grades				Special optical grades			
Grade	Makrolon® 2205/ 2207	Makrolon® 2405/ 2407	Makrolon® 2605/ 2607	Makrolon® 2805/ 2807	Makrolon® OD2015	Makrolon® LED2045/ LED2245**	Makrolon® LED2245	Makrolon® AL2447/ 2647
Color code	550115	550115	550115	550115	000000	000000	550207	550396/551070**
Color	Crystal clear	Crystal clear	Crystal clear	Crystal clear	Non-tinted	Non-tinted	Ice color	Crystal clear
MVR (cm^3/10 min @300°C)*	36	19	12	10	61	61 36	36	19 12
Transmission Ty (4 mm)*	87-88 %	87-88 %	87-88 %	87-88 %	90 %	90 %	89 %	88 %
Application	General purpose grade	General purpose grade	General purpose grade	General purpose grade	Optical grade CD/DVD	Light guides, collimator optics	LED lenses	Head lamp lenses
UV-protected	no/yes	no/yes	no/yes	no/yes	no	no	no	yes

* typical value, no specification
** availability depends on region

Bayer MaterialScience also offers materials for medical technology and food contact applications, as well as for the corrective eyewear industry. Very high purity requirements are also fulfilled in these fields of application, although other regulatory requirements have higher priority. For this reason, they are not discussed further here; refer to the corresponding brochures.

All values are typical, not specified values.

A | Transmission spectra

Makrolon® has high optical transmission in the visible range and in the near-infrared range to about 1100 nm. Makrolon® absorbs light in the UV range and in the infrared range > 1100 nm.
Transmission spectra are shown below (Figure 1).

In the case of clear, transparent grades, a distinction is made between different color formulations:

- The color "natural" refers to the color of the basic material without color correction. If viewed across an edge, for example, it appears to have a slightly yellow cast. The color code is 000000.
- A slightly bluish tint lends the material a fresher-looking color called "crystal clear." With the blue correction, some transmittance is lost, particularly in thick-walled articles. The most common color code is 550115.
- A special variation of "crystal clear" is "ice color," as in Makrolon® LED2445HC 551056. Even in thick-walled articles, this material still displays high transmittance, although it is perceived as having a slightly bluish cast.

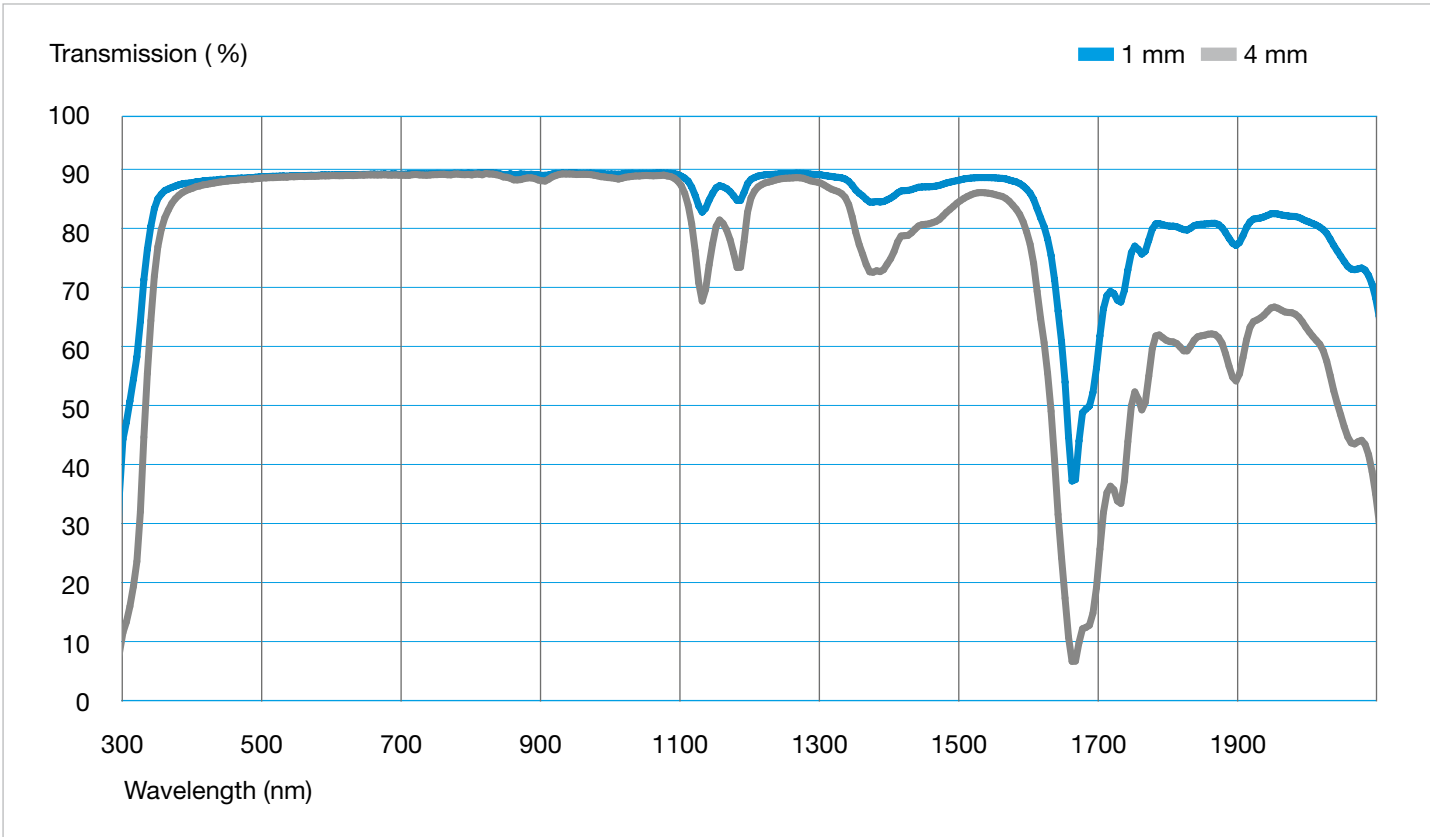


Figure 1: Transmission spectra of Makrolon® OD2015 (1 mm and 4 mm)

The optical blue impression of “crystal clear” is preferred for standard injection moldings. In the case of long light paths, such as in thick-walled lenses or optical fibers, the inherent loss of transmittance in blue-tinted materials can be high, and processors should choose natural color or icecolor grade instead. This behavior is illustrated in Figure 2. Please be aware that Makrolon® LED2045 000000 and Makrolon® LED2245 000000 show very similar transmission spectra and Ty properties (Figure 2+3). Also Makrolon® AL2647 550396 shows very similar transmission spectra and Ty properties compared to Makrolon® AL2447 550396, Makrolon® AL2647 551070 and Makrolon® AL2447 551070.

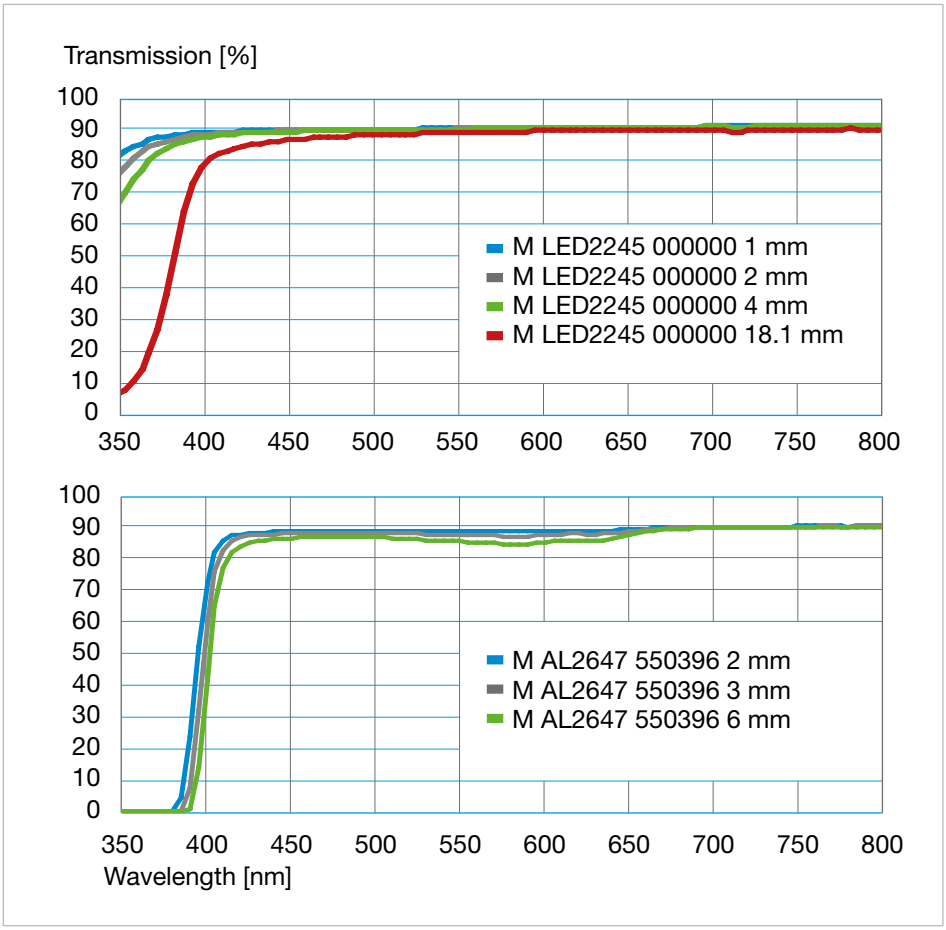


Figure 2: Transmission spectra of Makrolon® LED2245 000000 and Makrolon® AL2647 550396 at various wall-thicknesses

The same behavior is observed if the compressed form of transmittance Ty is selected instead of the wavelength dependent form of the transmission spectra as shown in Figure 3.

Other color characterization methods include haze, the yellowness index, as well as the absolute and relative color coordinates.

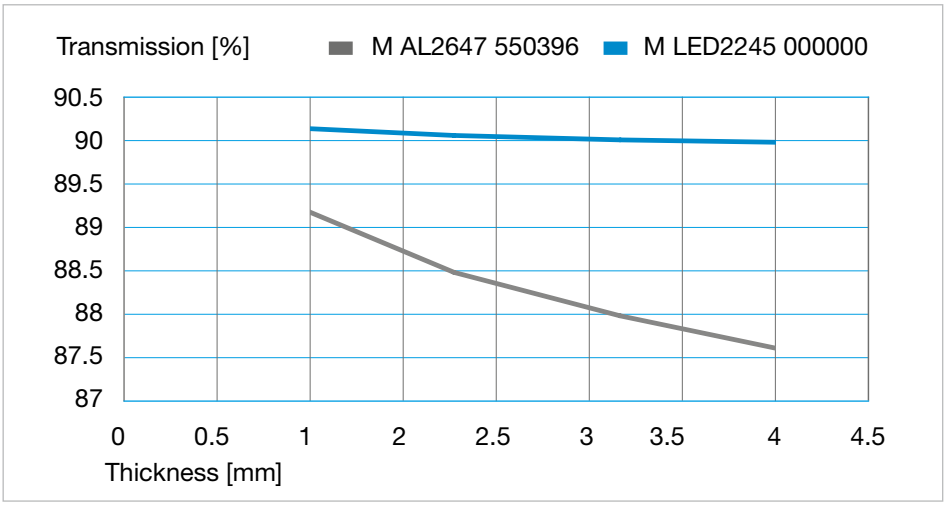


Figure 3: Transmission Ty as a function of wall thickness, Makrolon® LED2245 000000 and Makrolon® AL2647 550396

All values are typical, not specified values.

B | Refractive index

The refractive index of Makrolon® is wavelength-dependent, as shown in Figure 4 for Makrolon® LED2245 000000. The corresponding Abbé number is 30. The Abbé number is defined as [n(589 nm)-1]/[n(486 nm) – n(656 nm)].

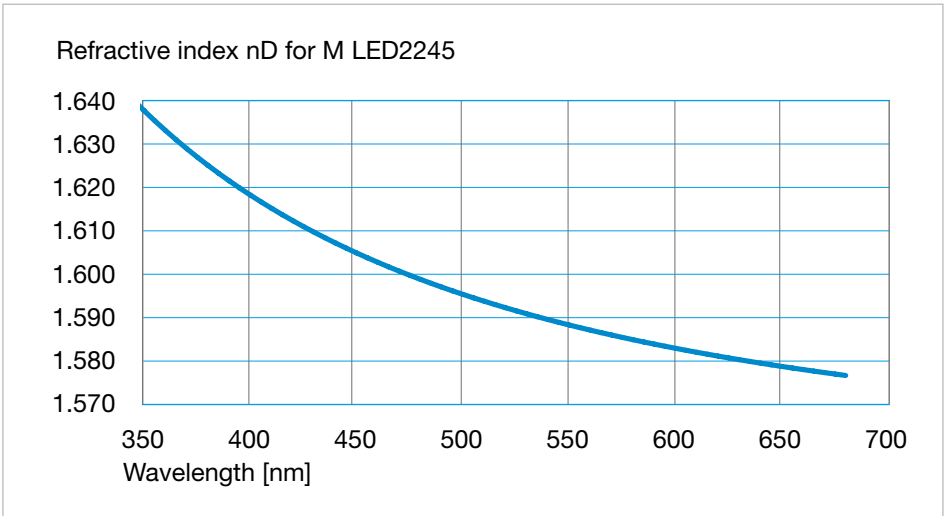


Figure 4: Refractive index as a function of wavelength for the representative Makrolon® LED2245 000000

The other transparent Makrolon® grades have a very similar refractive index compared to Makrolon® LED2245 000000. Details are available on request.
The dependence of Makrolon's® refractive index nD on temperature can be clearly illustrated by Makrolon® LED2245:
The nD value drops linearly as the temperature increases from - 40 to 120 °C.

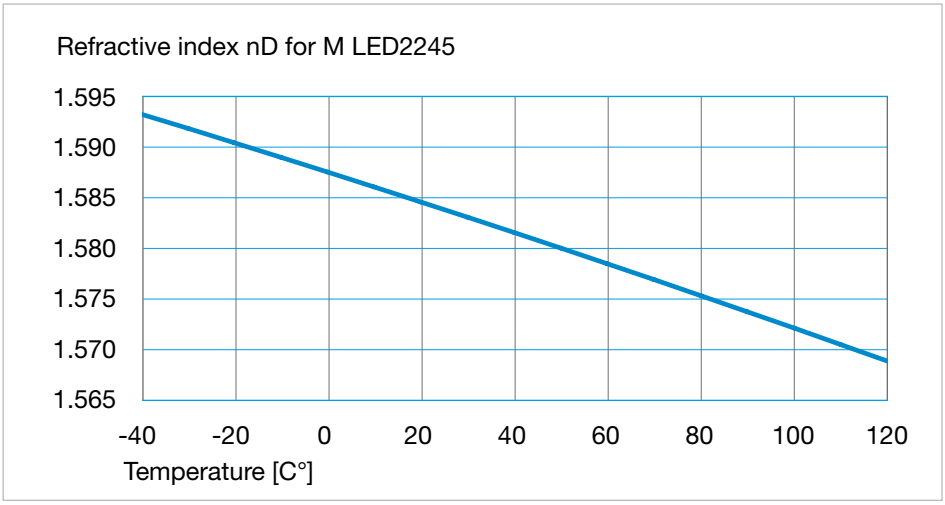


Figure 5: Refractive index of Makrolon® LED2245 as a function of temperature

C | Weathering properties

The most visually perceptible change in Makrolon® when exposed to UV light, either in the form of outdoor weathering or artificial UV-emitting light sources, is yellowing.
Other properties that deteriorate with weathering/UV exposure are:

Failure modes:

- Decreased transmission due to increased yellowing and haziness of the Makrolon®.
- Bleaching of tinted Makrolon®, both transparent and colored grades.
- Deterioration in surface properties, such as cracking and haze formation caused by extensive UV exposure.
- Deterioration in mechanical properties, e.g. impact strength and stiffness, due to the decomposition of Makrolon® initiated by UV light.

Therefore, UV stabilization is essential when parts made of Makrolon® are expected to withstand intensive UV exposure and harsh weather conditions. Based on state-of-the-art technologies, extensive product know-how and decades of experience, Bayer MaterialScience has developed various UV-protection solutions for Makrolon®, of which the most widely applied are (Figure 6):

Approaches:

- UV absorber embedded in Makrolon® resin.
- Hardcoat concentrated with UV absorber.
- Coextruded Makrolon® layer concentrated with UV absorber.
- Combination of two or more of the above strategies.

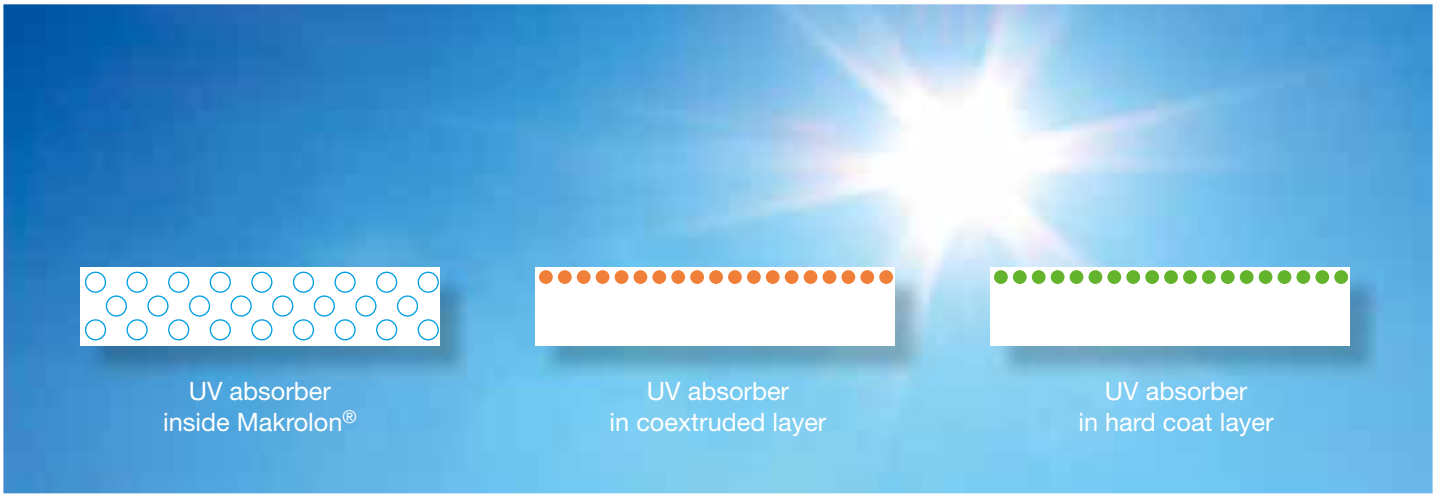


Figure 6: Strategies for protecting Makrolon® against UV exposure and outdoor weathering

As illustrated in Figure 7, the efficiency of the two strategies, i.e. UV absorber inside Makrolon® base material and UV absorber in coextruded layer, is evaluated quantitatively by precisely measuring the yellowness index YI (ASTM E313) over the testing period.

The coextruded Makrolon® layer and then the hardcoat concentrated with UV-absorber provide very efficient UV-protection for extruded and injection-molded Makrolon® products exposed to intense outdoor weathering. Depending on the applications, a lifetime of up to 20 years is achievable for coextruded Makrolon® sheets, as well as 3 – 12 years (3 – 6 years Florida or 6 – 12 years Germany) for hard-coated, injection-molded Makrolon® parts (4 mm thickness).

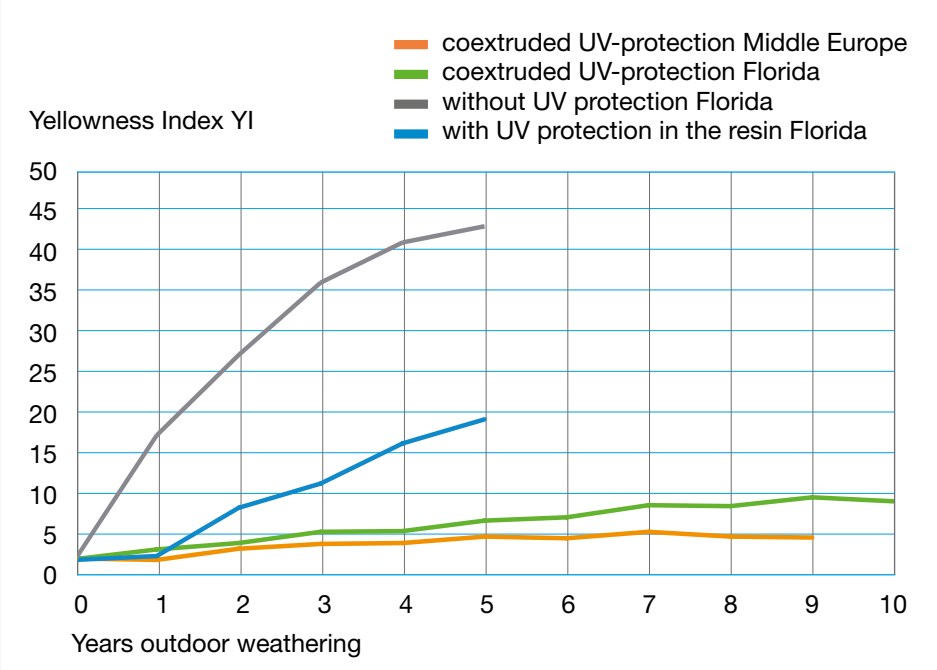


Figure 7: Quantitative comparison of different UV stabilization solutions

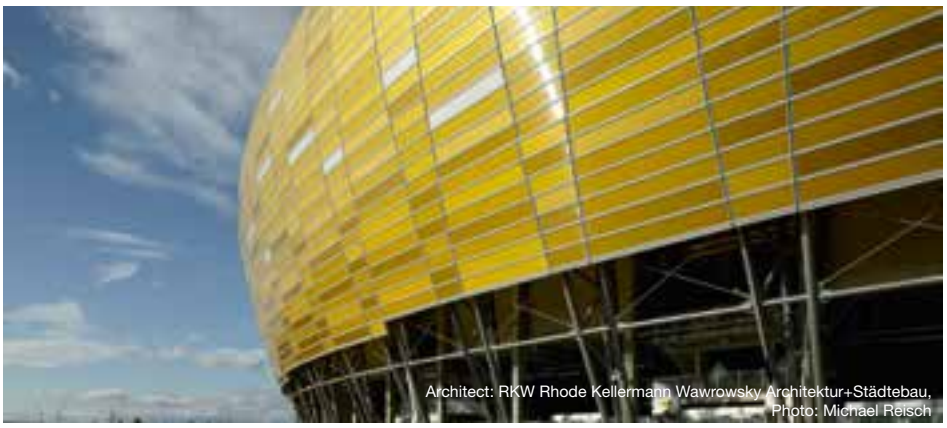


Figure 8: Examples of UV-protected, coextruded Makrolon® sheets

Figure 9: Examples of UV-protected, injection-molded Makrolon® parts with hardcoats

D | Temperature resistance

Components made of Makrolon® typically display high temperature resistance. A distinction is made between short-term temperature resistance and long-term temperature resistance. Different methods exist for measuring short-term temperature resistance, such as the glass transition temperature, Vicat softening point and heat distortion temperature (HDT). The short-term temperature resistance is comparably high within the group of clear, transparent Makrolon® grades. Extended exposure to extreme temperatures leads to yellowing over time, depending on the temperature.

The kinetics of yellowing also depend on the individual Makrolon® grade. Makrolon® LED2245 000000 and Makrolon® LED2045 000000 display the lowest tendency towards yellowing. This behavior is illustrated for Makrolon® LED2245 000000 in Figure 10.

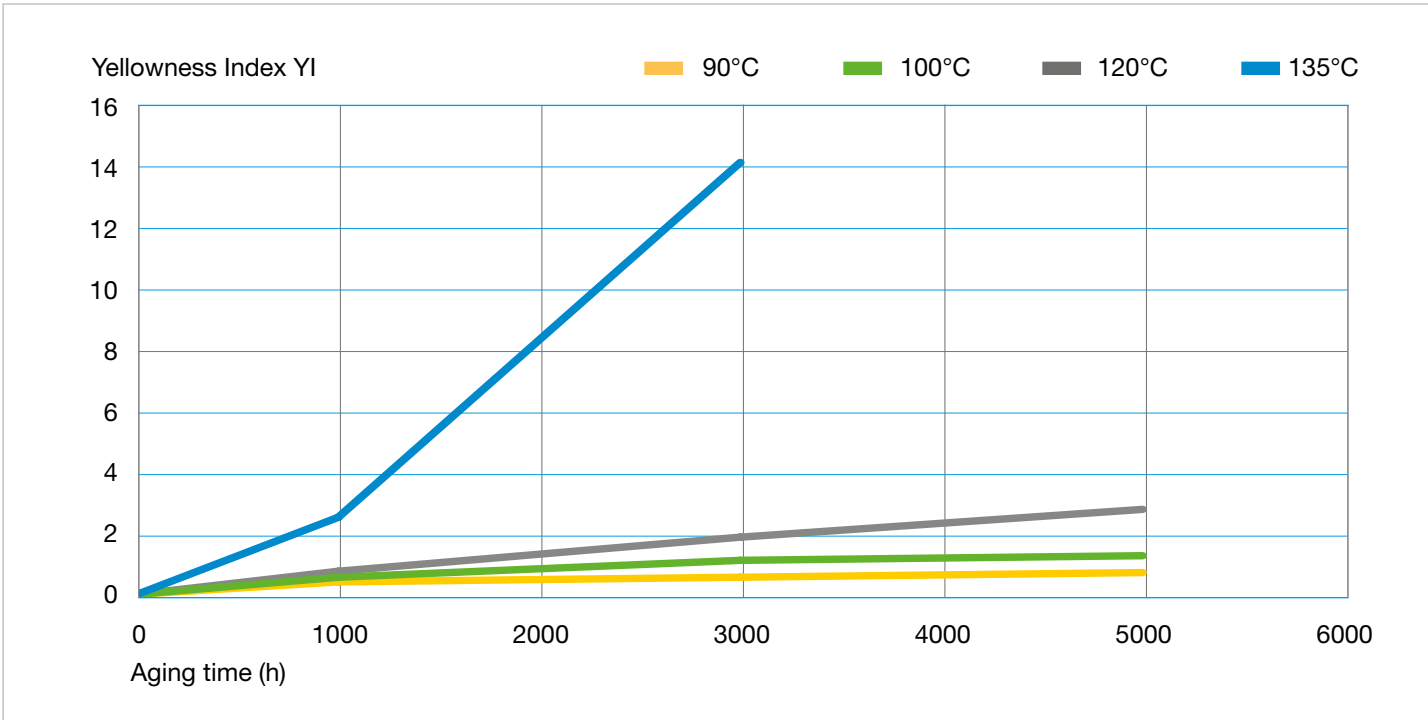


Figure 10: Thermal aging of Makrolon® LED2245 000000 (4 mm) at different temperatures

Figure 10 shows that Makrolon® LED2245 000000 displays a very low tendency towards yellowing at temperatures up to 120 °C. In contrast, discoloration occurs much more rapidly at 135 °C.

Apart from yellowing, other changes in properties can also occur after extended exposure to high temperatures. However, yellowing is the first indication; other phenomena, such as loss of transmittance or the gradual appearance of a cloudy haze, occur only after even longer exposure to heat. Nonetheless, the mechanical properties, such as good impact strength, remain on a high level even after an extended period of time.

All values are typical, not specified values.

E | Aging under artificial light sources

LEDs, halogen lamps and gas discharge lamps are artificial light sources with high radiant intensity. The question often arises as to how resistant Makrolon® is to these light sources. Clear, transparent Makrolon® basically is very resistant to these light sources, even at a high radiant flux, provided they contain no UV light (<400 nm). For example, suitable, UV-absorbing glass bulbs can filter out residual UV radiation. In the case of minimal UV fractions, and when using tinted Makrolon® grades, a case study must be conducted that gives consideration to the light source's emission spectrum and the additional temperature exposure that frequently prevails.
LEDs are a special case. At moderate radiant intensities, all clear and transparent Makrolon® grades are very resistant to LED light. However, high radiant intensities or LEDs with peak wavelengths less than 450 nm may still lead to material damage. To fulfill the stringent requests of demanding applications, e.g. automotive headlamps, Bayer MaterialScience has developed specialty polycarbonate Makrolon® LED grades, which are easy-flowing, highly transparent and have particularly high resistance to LED light.

Figure 11: LED headlamp in the Audi A8 using Makrolon® LED2245 for low beams and daytime running lights

3 Signal Colors

Makrolon® and Apec® are available in almost any transparent color.

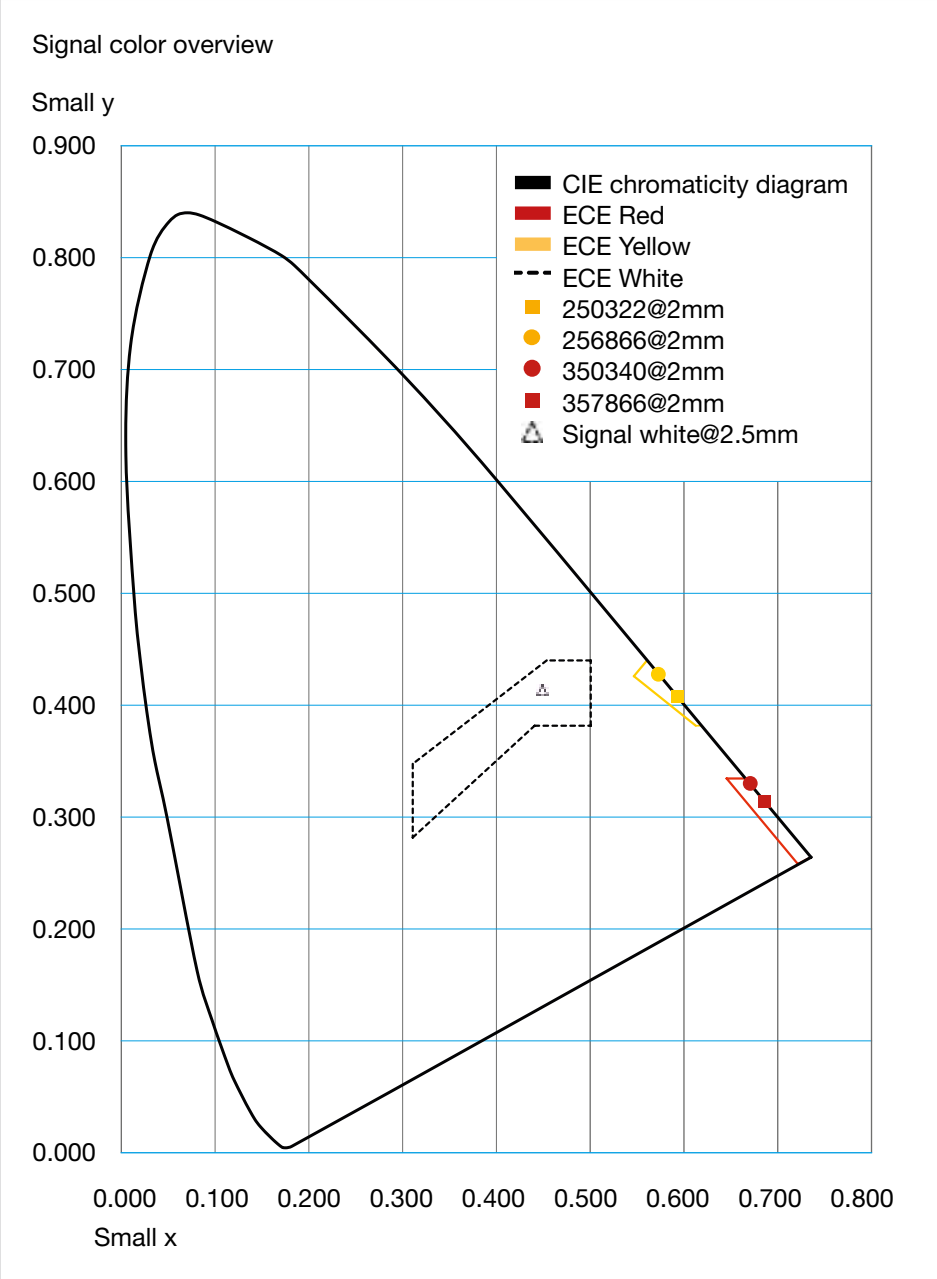


Figure 12: Positions of the main signal color ranges in the CIE chromaticity diagram (typical color coordinates; may vary within tolerance)

Makrolon® and Apec® transparent signal colors have been used for many years in various applications, such as automotive lighting, signal transmitters and signal lights. Furthermore, thanks to their excellent mechanical properties and very high heat resistance, Makrolon® and Apec® are not only qualified for standard applications, such as turns signals, rear lights, traffic lights and warning lights on emergency vehicles, but also ideal for harsher environments, e.g. in aircraft, rail and shipping applications. Figure 12 shows the current range of signal colors in accordance with the standard specifications in the CIE chromaticity diagram. Some of the typical signal colors – white, yellow and red – are shown in the diagram to represent the large number of signal colors available.

All values are typical, not specified values.

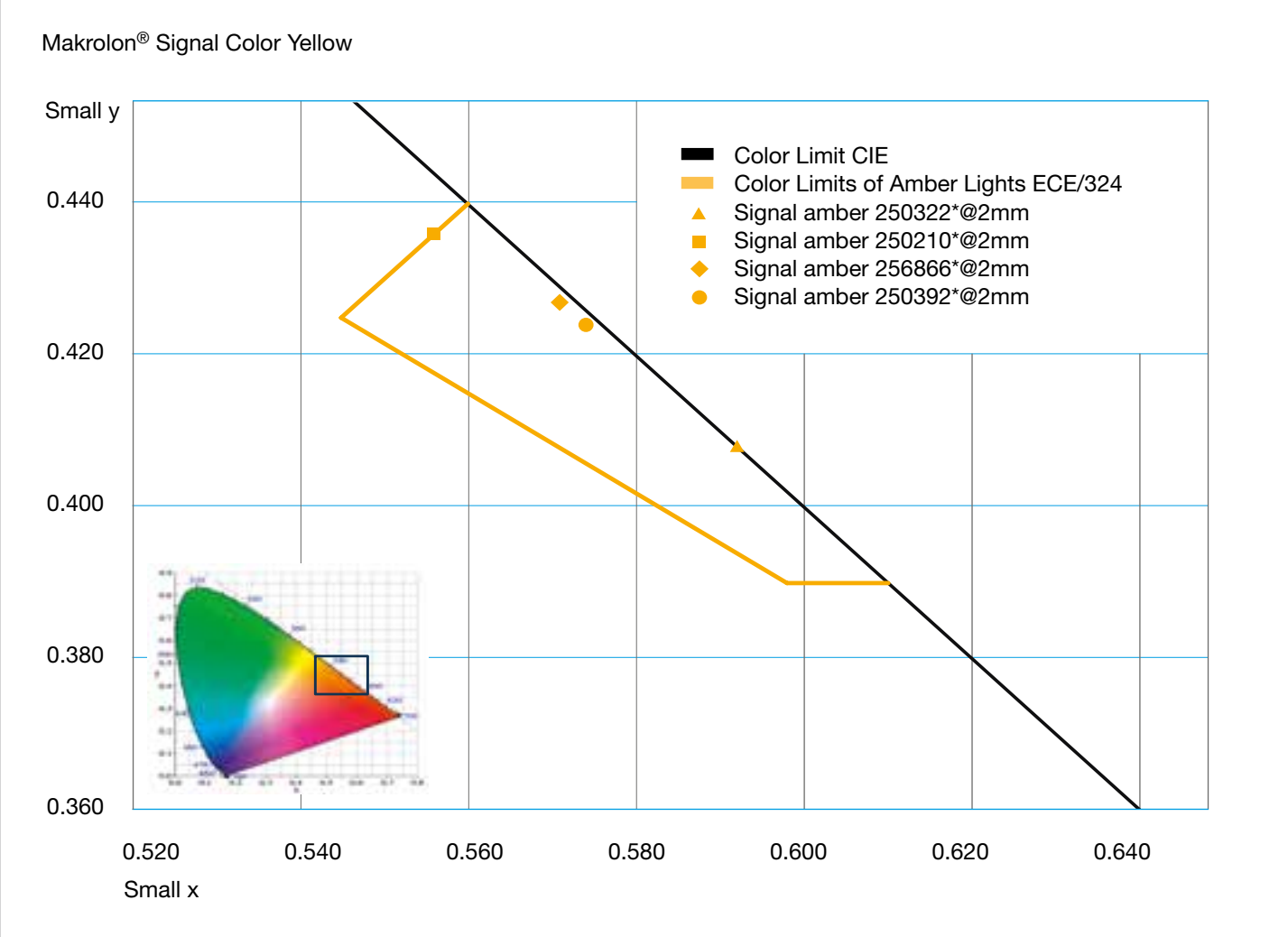


Figure 13: Position of the yellow signal range in the CIE chromaticity diagram and important signal colors
*Typical color coordinates; may vary within tolerance

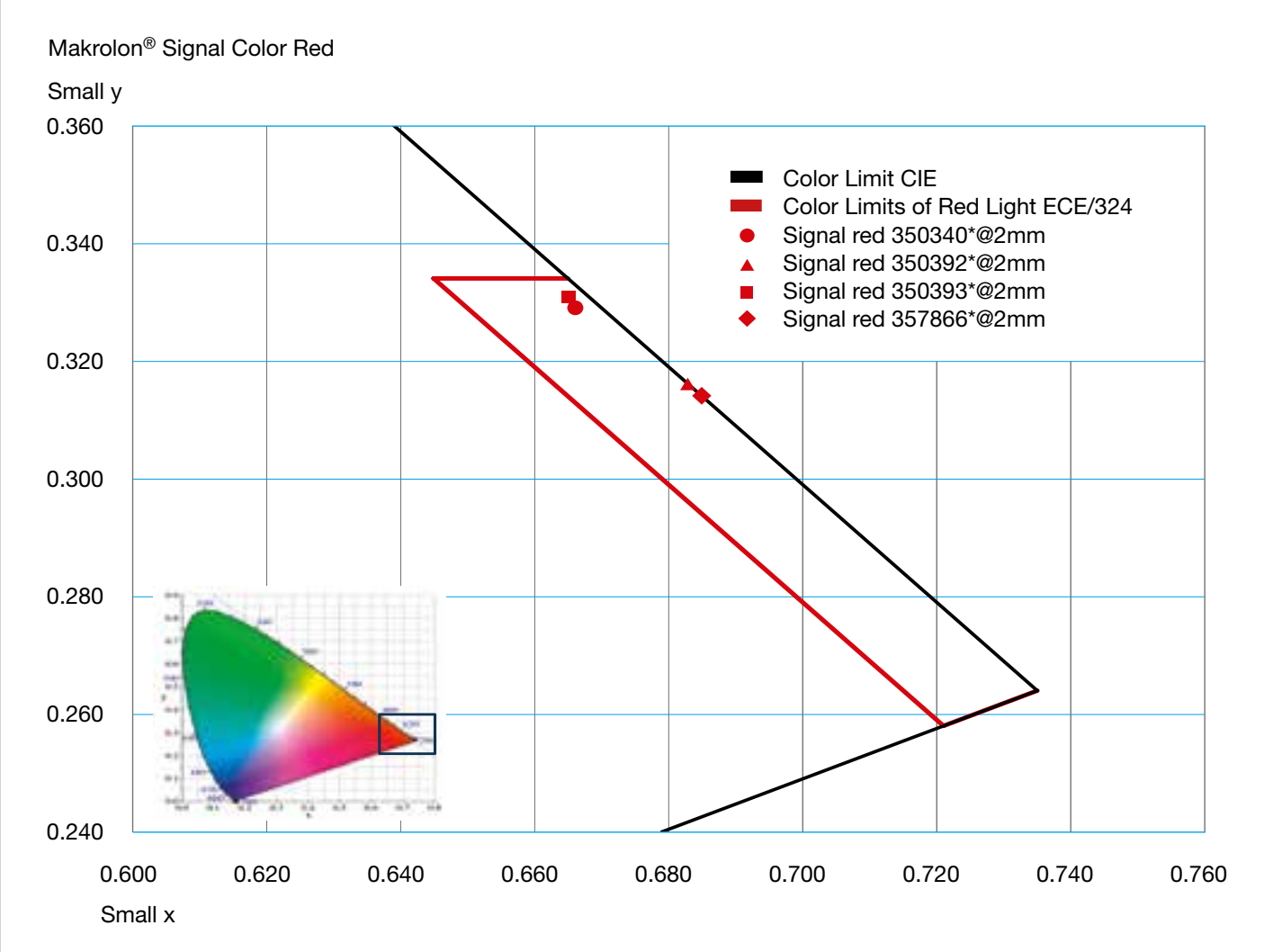


Figure 14: Position of the red signal range in the CIE chromaticity diagram and important signal colors
*Typical color coordinates; may vary within tolerance

The colorimetric guide data for the signal colors were calculated in accordance with light type A, 2° observer. Figures 13 and 14 show the exact positions of several of the most common yellow and red signal colors in automotive lighting in the CIE chromaticity diagram. It should be noted that wall thickness influences not only the transmittance, but also the color parameters, meaning that colors for wall thicknesses other than 2 mm (Figs. 13 and 14) will appear at different positions in the CIE chromaticity diagram.

4 High-reflectance white

Characterized by their high efficiency in reflecting visible light, high-reflectance white Makrolon® grades are noted for their increasing application as ideal raw materials for LED lamp reflectors. Other applications include construction, lighting, automotive and household appliances. A reflection ratio as high as ca. 95 % can be achieved. Figure 15 shows the reflectance spectra in the visible range of several representative colors.

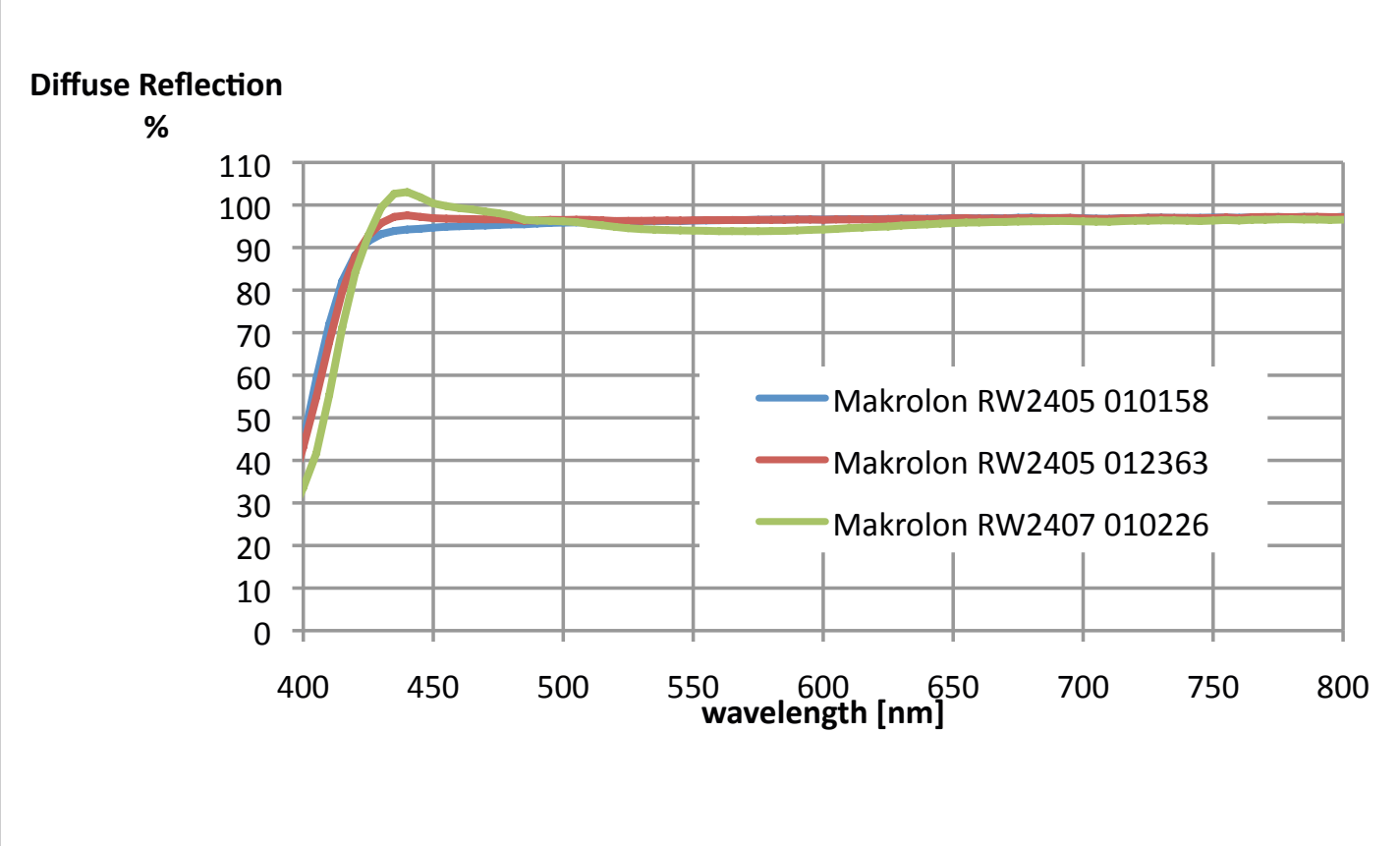


Figure 15: Reflectance spectra of several high-reflectance white Makrolon® colors

5 Special colors

A | NIR-transparent black

Black-tinted Makrolon® normally has the color code 901510. This material exhibits very high surface quality and high gloss. The color is very resistant to the effects of light and largely opaque to visible and infrared light.
Special color formulations were developed that appear to be black, but display high transmittance in the near-infrared range (NIR). In addition to very high surface quality and high gloss, these color formulations also show an enhanced depth effect.
These NIR-transparent colors can be used for aesthetic reasons, and for applications in which high transmittance in the NIR is required, e.g. signal transmission in the NIR, such as light barriers and remote controls, and in joining processes, such as laser welding in the NIR.
Color formulations are available with different spectra (Figure 16).

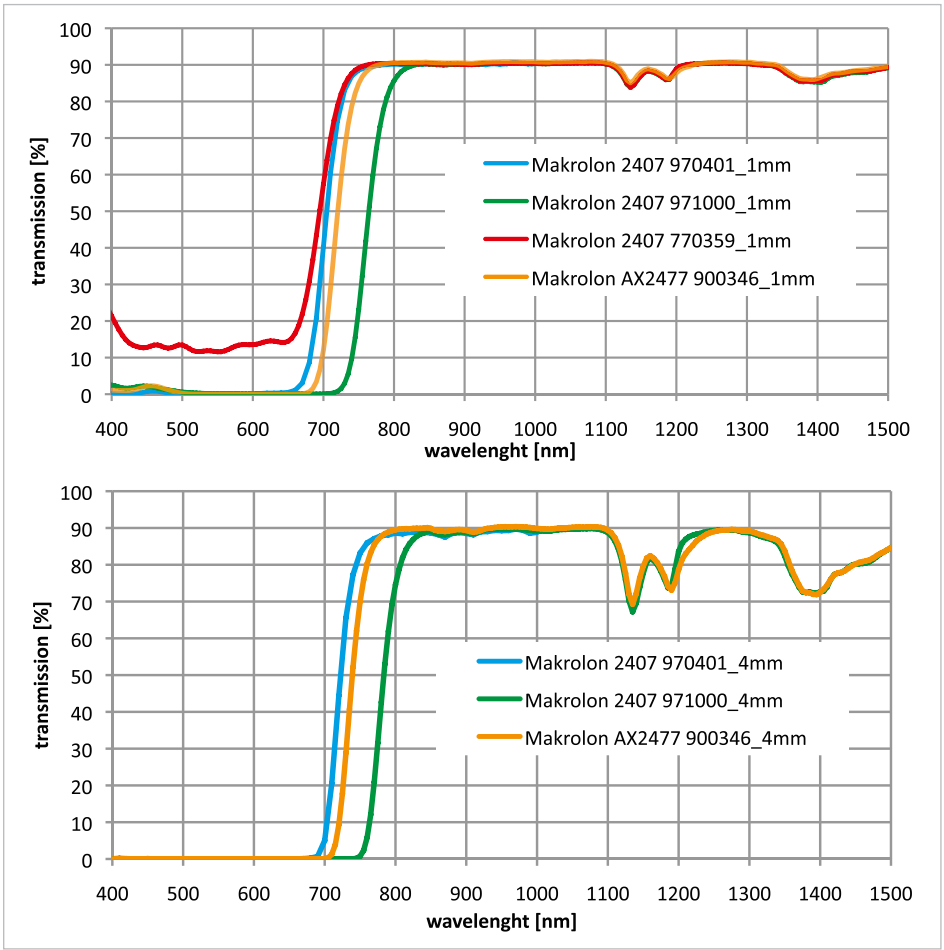


Figure 16: Transmission spectra of NIR-transparent color shades for thicknesses of 1 mm and 4 mm

B | NIR-absorbing grades

In addition to NIR-transparent black, Bayer MaterialScience also developed specialty color formulations featuring high absorption in the NIR but high transmittance in the visible range. These characteristics are particularly required, for instance, in automotive sunroofs made of Makrolon®AG to reduce the penetration of heat into the interior, or in various types of protective eyewear. Details are available on request.

C | Laser-marking colors

Makrolon® can be inscribed using commercial laser systems.
Bayer MaterialScience offers a variety of color formulations that support enhanced contrast, both in the color and in better resolution.
Details are available on request.

All values are typical, not specified values.

6 Translucent grades

Bayer MaterialScience offers various translucent grades with different transmittance, scattering properties and color impression.

Four colors, 021180, 021172, 021173 and 021182, are selected as examples for our wide portfolio of translucent grades. In this section, the properties of the sample set are described.

Please be aware that in NAFTA we offer similar colors but with different color code. Please contact us for details.

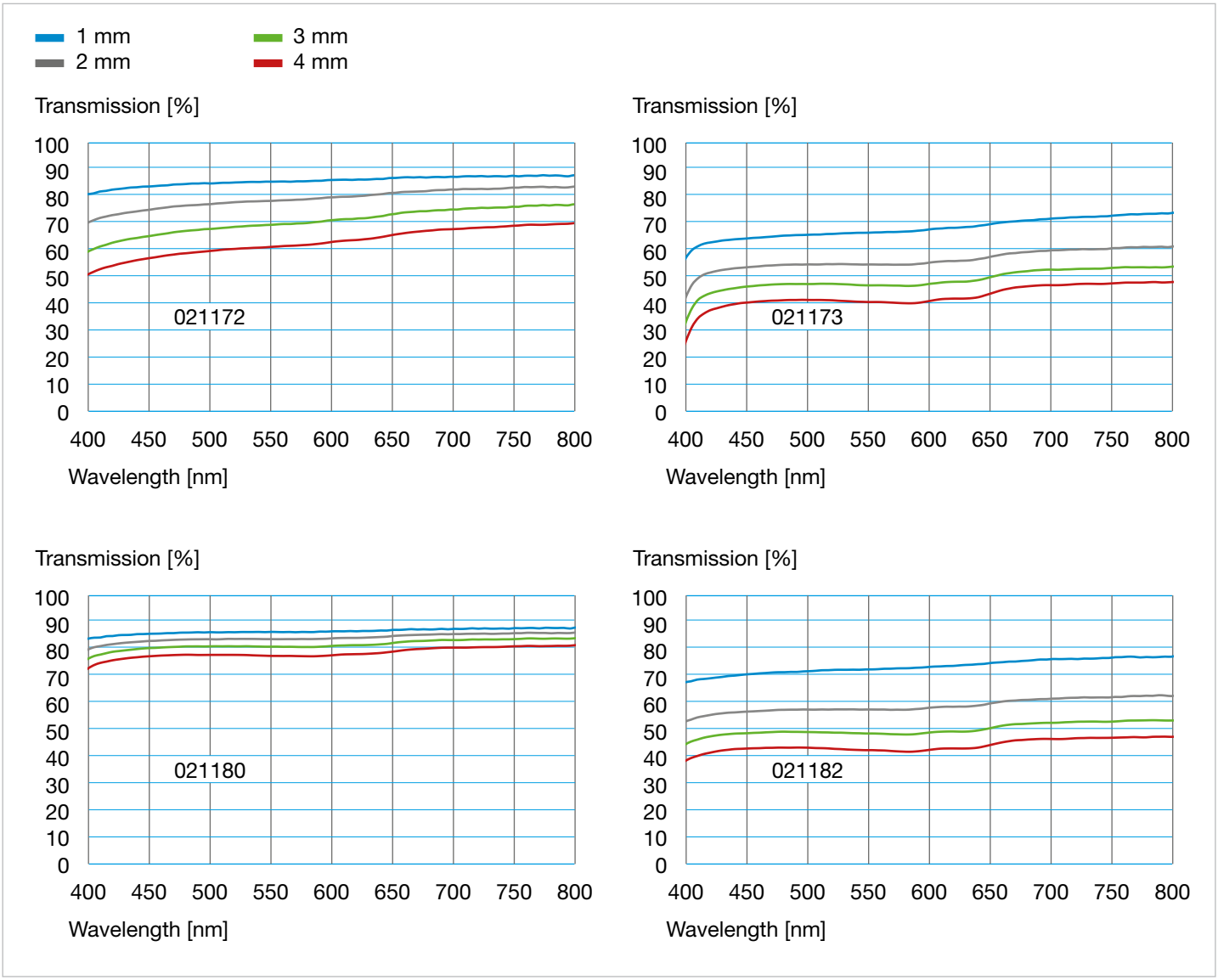


Figure 17: Transmission spectra of the selected grades in different thicknesses

To characterize the scattering properties, the following setup is usually chosen. The sample is covered by a mask with a small hole and is illuminated from the back. The light intensity shining through the whole is determined under different angles with a goniometer (see Figure 18).
The angle at which the light intensity is reduced to half of the maximum is called the “half-power angle” (HPA). The bigger the half-power angle is, the stronger the scattering efficiency will be.

Other methods to characterize scattering properties include e.g. diffusion factor DF or hiding power HP. The half-power angle can also be determined by “luminosity”, which leads to a different HPA value than in the case of light intensity. All HPA values mentioned in this chapter are measured based on light intensity.
Translucent properties can be achieved by adding special scattering agents. Increasing the dosage of scattering agents leads to increase of the half-power angle, while the luminous transmission will decrease. Same with sample thickness: Thicker samples result in a bigger half-power angle and lower luminous transmission. Therefore, it is the challenge for each application to find the right balance. This behavior is shown for thicknesses of 1, 2, 3 and 4 mm in Figure 19.

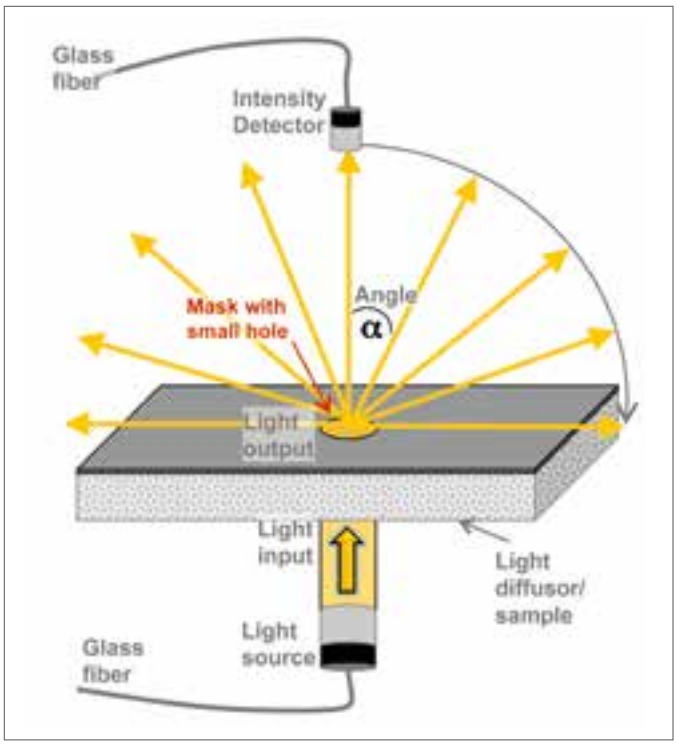


Figure 18: Goniometer measurement setup

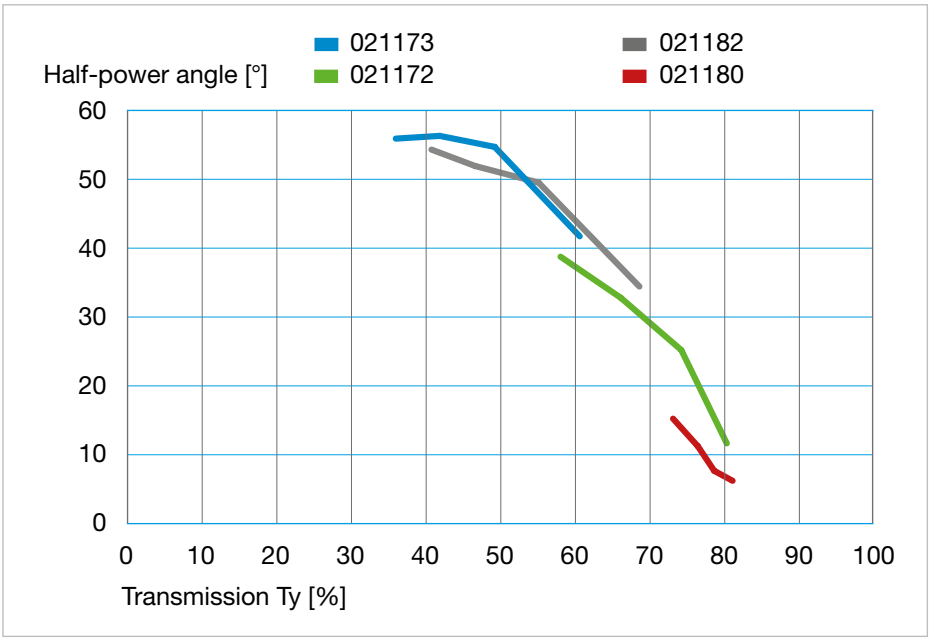


Figure 19: Half-power angle and transmission of selected translucent colors

In Figure 19, it can be seen that 021180 has the highest transmission but also the lowest scattering performance, whereas 021173 has the best scattering performance but also the lowest transmission. The various results are shown in Table 3.

All values are typical, not specified values.

Color code	Thickness (mm)	Hunter Ultra ScanPR Ty (D65 10°) (%)	Byk Gardner haze guard Haze (%)	Photogoniometer GON360 Instrument Systems Half-power angle (HPA) (°)	Diffusion factor (DF) (%)	Hiding power (HP) (%)
021180	1	84.2	72.0	2.4	2.28	58.2
	2	81.7	92.2	4.0	5.52	78.2
	3	79.3	97.8	7.6	10.12	90.6
	4	76.1	100.0	11.9	1.88	96.5
021172	1	83.4	98.6	7.9	14.4	85.7
	2	77.3	100.0	22.2	30.8	98.7
	3	68.7	100.0	30.2	39.5	99.6
	4	60.4	100.0	36.3	44.7	99.8
021173	1	63.2	100.0	39.4	47.9	98.2
	2	51.6	100.0	52.9	56.8	99.9
	3	44.1	100.0	54.5	57.9	99.0
	4	37.8	100.0	54.1	57.6	100.0
021182	1	71.4	100.0	31.8	42.4	97.0
	2	57.4	100.0	47.7	53.2	99.8
	3	49.0	100.0	50.1	54.7	99.8
	4	42.7	100.0	52.7	54.5	99.9

Table 3: Scattering properties of translucent grades (typical values, no specification)

In some publications, the scattering performance is visualized by polar coordinates. This is shown for our materials in Figure 20.

In Figure 20, the theoretical limit of Lambertian scattering performance was added. This is to underline that the scattering performance, especially of colors 021182 and 021173, is close to the theoretical limit.

In order to help the customers to accelerate the material selection process, Bayer MaterialScience also offers standard color chips of various thicknesses as shown in Figure 21. Details are available on request.

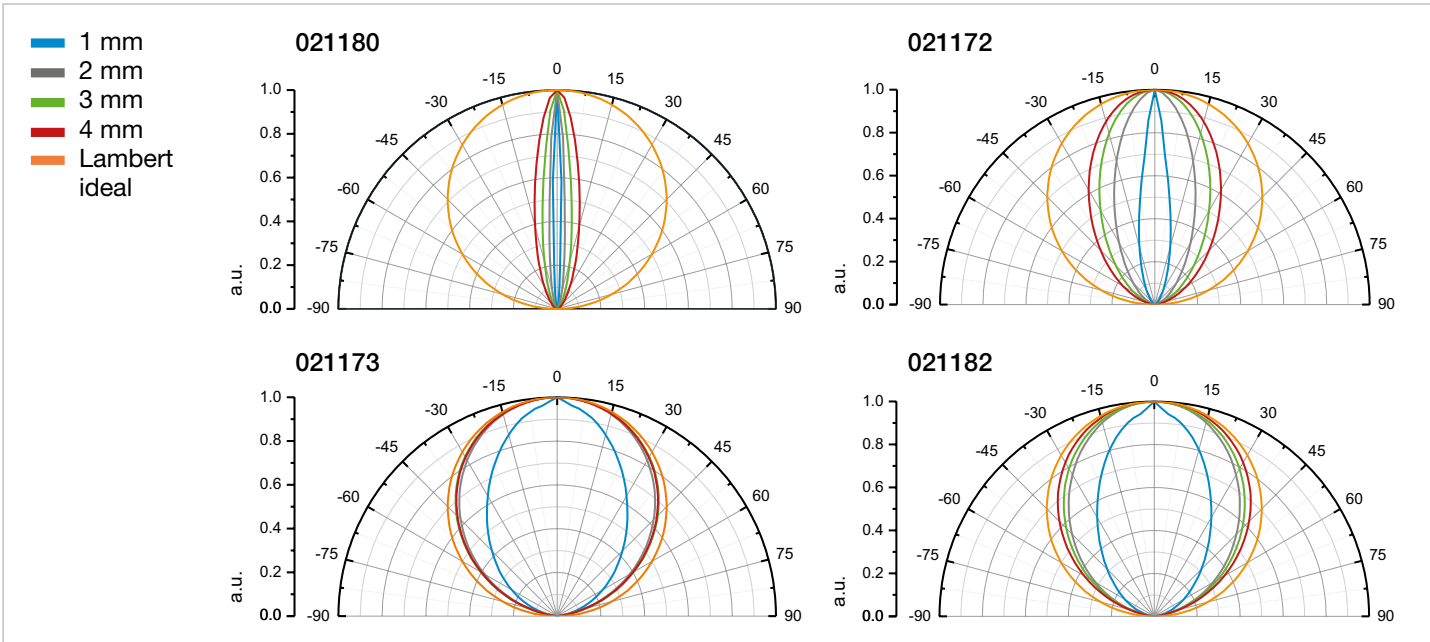
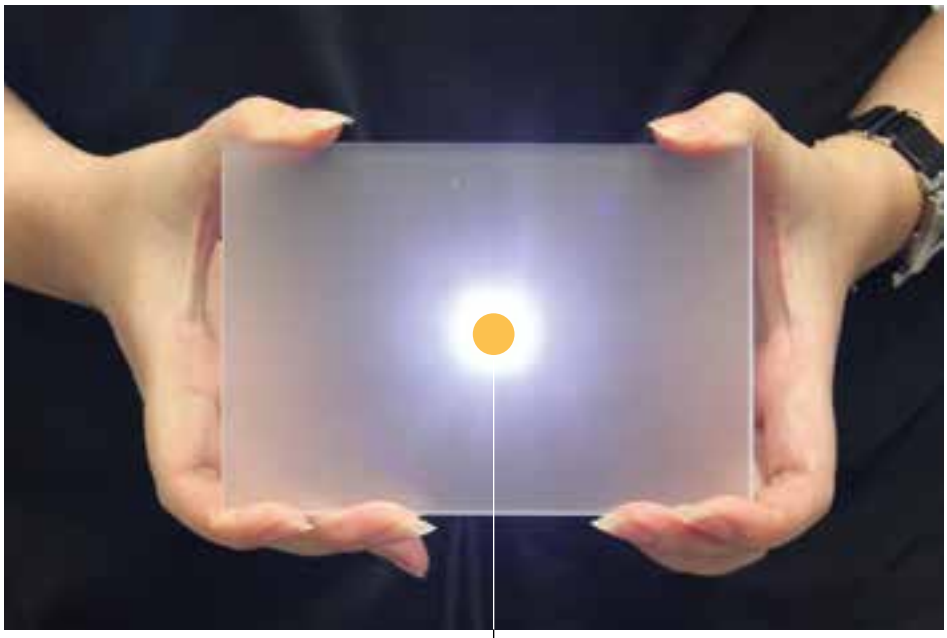


Figure 20: Scattering performance of translucent sample set expressed by polar coordinates

Figure 21: Illustration of scattering performance by simple experiment

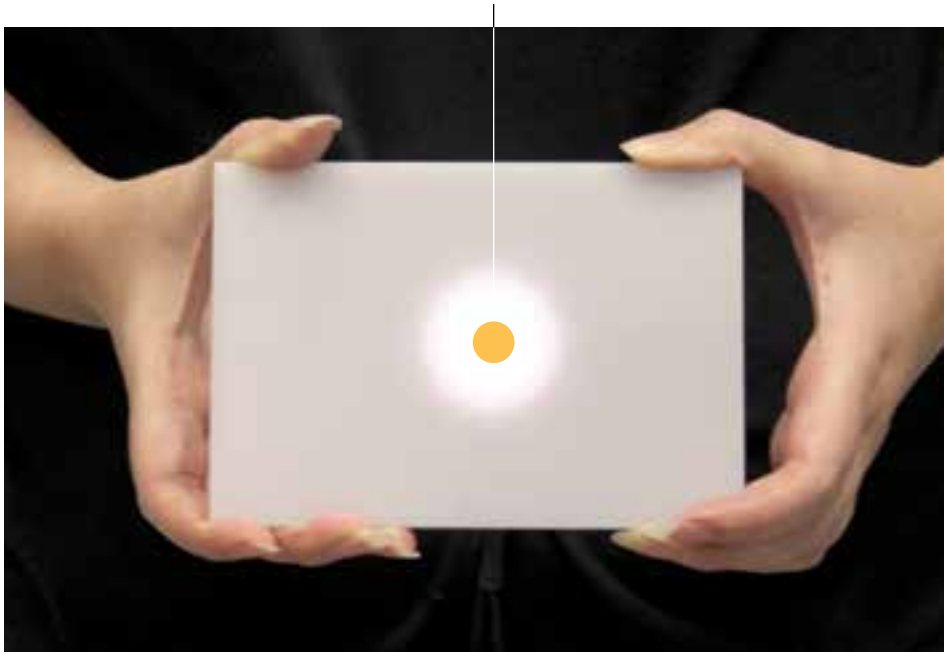
Sample illuminated by an LED pocket light, directly placed onto the rear side of the sample

Weakly scattering sample with high transmission:
- 021180 – 3 mm
- HPA = 8°
- Ty = 79.3 %



Original spot size

Highly scattering sample with low transmission:
- 021173 – 3 mm
- HPA = 54°
- Ty = 44.1 %



7 Apec® – High temperature resistant polycarbonate

Apec® is a further development of Makrolon® that offers even higher heat resistance. The copolycarbonate is made of bisphenol A (building block of Makrolon®) and another monomer, bisphenol TMC. Varying the ratios of the two components results in products having heat resistance values as high as 202 °C (Vicat softening temperature). The typical properties of the clear, transparent Apec® grades are summarized in Table 4.

	High-flow Apec® grades				High-viscosity grades	
Properties*	Apec® 1695/1697	Apec® 1795/1797	Apec® 1895/1897	Apec® 2097	Apec® 1703	Apec® 1803
Crystal-clear color	551022	551022	551022	551022	551022	551022
Vicat-Temperature (50N 120 K/h ISO306)	158 °C/157 °C	173 °C/172 °C	183 °C/182 °C	202 °C	171 °C	184 °C
Transmission Ty (1mm DIN5036-1)	89 %	89 %	89 %	89 %	89 %	89 %
Refractive index nD (ISO489A)	1.578	1.576	1.573	1.566	1.578	1.573
Abbé number	30	30	30	31	30	30
RTI relative temperature index (static yield stress) (UL746B)	140 °C	140 °C	150 °C	150 °C	150 °C	150 °C
UV protection	no/yes	no/yes	no/yes	yes	yes	yes
Additional approvals					AMECA	AMECA

* typical values, no specifications

Table 4: Optical properties of Apec® grades

Apec's® transmittance is comparable to that of Makrolon®:

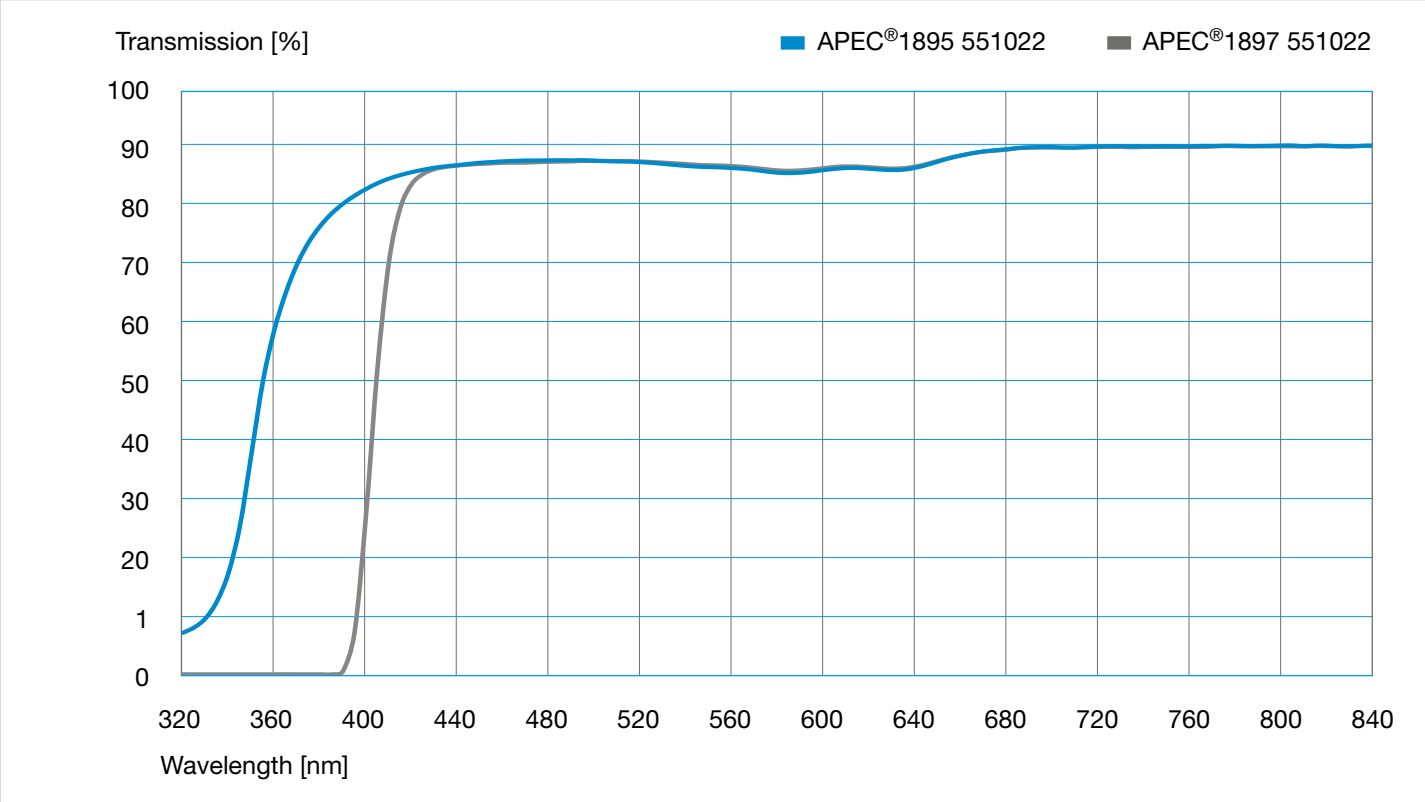


Figure 22: Transmission spectra of Apec® 1895 551022 and Apec® 1897 551022 (4 mm)

The variable composition of the Apec® grades is reflected by their refractive index (Figure 23).

As the bisphenol TMC content rises (rising heat resistance), the refractive index drops.

The dispersion of the refractive index is similar to that of Makrolon®, but shifted as a function of on the bisphenol TMC content.

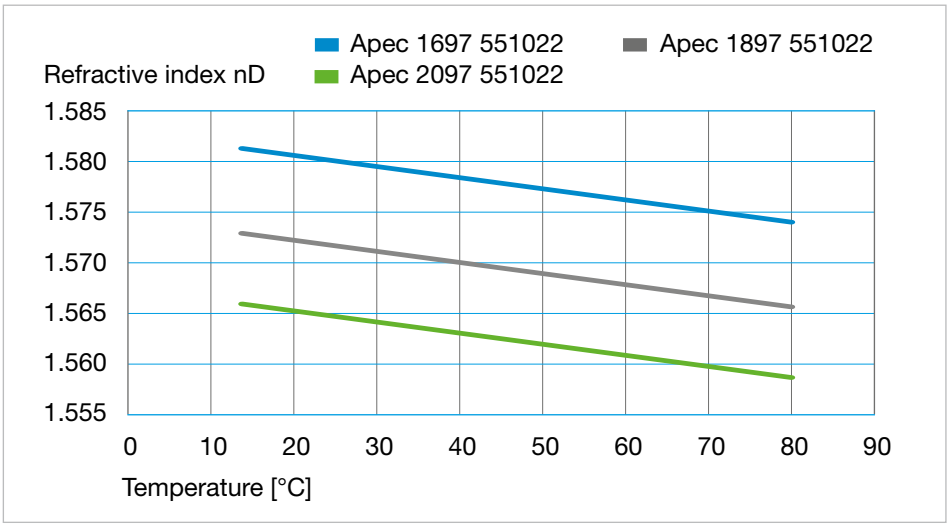


Figure 23: Refractive index nD as a function of temperature.

All values are typical, not specified values.

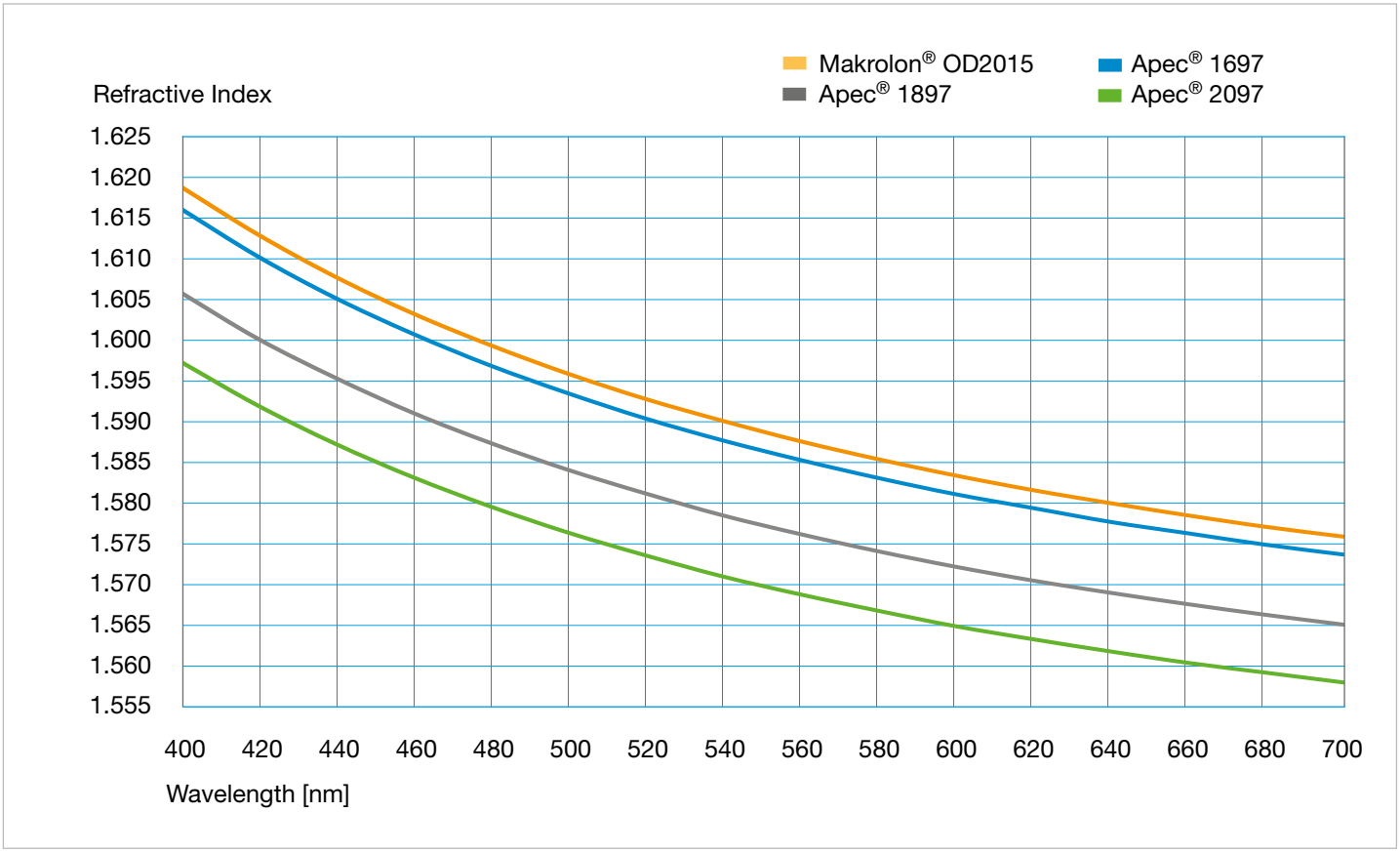


Figure 24: Refractive index as a function of wavelength

Apec® grades are frequently used in Makrolon® applications where elevated temperatures occur, particularly in automotive lighting.

Detailed information on the Apec® grades is available in the brochure: "Overview of Apec® product grades – Reference values."

8 Appendix – Typical properties of Makrolon® and APEC®

Makrolon®				Standard grades								Optical grades					
Properties	Test conditions	Units	Standards	Low-viscosity								Optical-data-storage	Eye-wear	Light-guide		Automotive-lighting	
				2205	2207	2405	2407	2605	2607	2805	2807	OD2015	LQ2647	LED2045	LED2245	AL2447	AL2647
Rheological properties																	
C Melt volume-flow rate (MVR)	250 °C; 2.16 kg	cm³/10 min	ISO 1133									17		17			
C Melt volume-flow rate (MVR)	300 °C; 1.2 kg	cm³/10 min	ISO 1133	34	34	19	19	12	12	9.0	9.0		12		34	19	12
Melt mass-flow rate (MFR)	300 °C; 1.2 kg	g/10 min	ISO 1133	37	37	20	20	13	13	10	10		13		37	20	13
Molding shrinkage, parallel	60x60x2; 500 bar	%	ISO 294-4	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.6	0.65	0.6	0.65	0.65	0.65
Molding shrinkage, normal	60x60x2; 500 bar	%	ISO 294-4	0.65	0.65	0.65	0.65	0.7	0.7	0.7	0.7	0.6	0.7	0.6	0.65	0.65	0.7
Mechanical properties (23 °C/50 % r. F.)																	
C Tensile modulus	1 mm/min	MPa	ISO 527-1,-2	2400	2400	2400	2400	2400	2400	2400	2400	2350	2400	2350	2350	2400	2400
C Yield stress	50 mm/min	MPa	ISO 527-1,-2	65	65	65	66	66	66	66	66	63	67	63	63	66	67
C Yield strain	50 mm/min	%	ISO 527-1,-2	6.0	6.0	6.0	6.0	6.1	6.1	6.2	6.1	5.9	6.1	6.0	6.0	6.0	6.1
C Nominal strain at break	50 mm/min	%	ISO 527-1,-2	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50	> 50
Flexural modulus	2 mm/min	MPa	ISO 178	2350	2350	2350	2350	2400	2400	2400	2400	2350	2400	2350	2350	2350	2400
3.5 % flexural stress	2 mm/min	MPa	ISO 178	73	74	73	74	73	74	73	74	72	74	72	73	74	74
Flexural strength	2 mm/min	MPa	ISO 178	97	98	97	98	97	98	97	98	97	98	97	97	98	98
C Charpy impact strength	23 °C	kJ/m²	ISO 179-1eU	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Charpy notched impact strength	23 °C; 3 mm	kJ/m²	ISO 7391/i.A. ISO 179-1eA	55P(C)	55P(C)	65P	65P(C)	70P	70P	75P	75P	50P(C)	70P	50P(C)	60P(C)	65P(C)	70P
Charpy notched impact strength	-30 °C; 3 mm	kJ/m²	ISO 7391/i.A. ISO 179-1eA	12C	12C	14C	14C	16C	14C	16C	14C	12C	14C	12C	12C	14C	14C
Izod notched impact strength	23 °C; 3 mm	kJ/m²	ISO 7391/i.A. ISO 180-A	65P(C)	65P(C)	75P(C)	75P(C)	70P	70P	75P	75P	55P(C)	80P(C)	50P	60P(C)	75P(C)	80P(C)
C Puncture maximum force	23 °C	N	ISO 6603-2	4900	4900	5100	5100	5400	5400	5400	5400	4700	5400	4700	4900	5100	5400
C Puncture energy	23 °C	J	ISO 6603-2	55	55	55	55	60	60	60	60	50	60	50	55	55	60
Thermal properties																	
C Temperature of deflection under load	1.80 MPa	°C	ISO 75-1,-2	124	123	124	124	125	123	125	124	124	123	124	125	125	123
C Temperature of deflection under load	0.45 MPa	°C	ISO 75-1,-2	137	136	137	136	136	135	137	136	138	135	137	138	138	136
C Vicat softening temperature	50 N; 50 °C/h	°C	ISO 306	145	143	145	143	144	143	144	143	145	143	145	145	144	143
C Coefficient of linear thermal expansion, parallel	23 bis 55 °C	10^{-4}/K	ISO 11359-1,-2	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
C Coefficient of linear thermal expansion, normal	23 bis 55 °C	10^{-4}/K	ISO 11359-1,-2	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
C Burning behavior UL 94 (1.5 mm)	1.5 mm	Class	UL 94	V2	V2	V2	V2	V2	V2	V2	V2		V2		V2	V2	V2
C Burning behavior UL 94-5V	3.0 mm	Class	UL 94	HB	HB	HB	HB	HB	HB	HB	HB		HB		HB	HB	HB
C Oxygen index	Method A	%	ISO 4589-2	28	28	27	27	28	28	28	28	28	28	27	28	28	28
Glow wire test (GWFI)	1.5 mm	°C	IEC 60695-2-12	875	875	875	875	850	850	875	875				875		
Glow wire test (GWFI)	3.0 mm	°C	IEC 60695-2-12	930	930	930	930	930	930	930	960				930		
Glow wire test (GWIT)	1.5 mm	°C	IEC 60695-2-13	875	875	875	875	875	875	875	875				875		
Glow wire test (GWIT)	3.0 mm	°C	IEC 60695-2-13	875	875	875	875	875	875	900	875				900		
Electrical properties (23 °C/50 % r. F.)																	
C Relative permittivity	100 Hz	-	IEC 60250	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
C Relative permittivity	1 MHz	-	IEC 60250	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
C Dissipation factor	100 Hz	10^{-4}	IEC 60250	5	5	5	5	5	5	5	55	5	5	5	5	5	
C Dissipation factor	1 MHz	10^{-4}	IEC 60250	90	90	90	90	90	90	90	90	95	90	90	95	90	90
C Volume resistivity	-	Ohm·m	IEC 60093	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14	1E14
C Volume resistivity	-	Ohm	IEC 60093	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16
C Electrical strength	1 mm	kV/mm	IEC 60243-1	34	34	34	34	34	34	34	34	34	34	34	34	34	34
C Comparative tracking index CTI	Solution A	Rating	IEC 60112	250	250	250	250	250	250	250	250	225	250	225	250	250	250
Other properties (23 °C)																	
C Water absorption (Saturation value)	Water at 23 °C	%	ISO 62	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
C Water absorption (Equilibrium value)	23 °C; 50 % r.F.	%	ISO 62	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
C Density	-	kg/m³	ISO 1183-1	1190	1190	1200	1200	1200	1200	1200	1200	1190	1200	1190	1190	1200	1200
Material specific properties																	
Refractive index	Methode A	-	ISO 489	1.584	1.584	1.585	1.585	1.585	1.585	1.586	1.586	1.584	1.585	1.584	1.584	1.585	1.585
Luminous transmittance (clear transparent materials)	1 mm	%	ISO 13468-2	89	89	89	89	89	89	89	89	> 89	89	90	90	89	89
C Luminous transmittance (clear transparent materials)	2 mm	%	ISO 13468-2	89	89	89	89	89	89	89	89		89	90	90	89	89
Luminous transmittance (clear transparent materials)	3 mm	%	ISO 13468-2	88	88	88	88	88	88	88	88		88	> 89	> 89	88	88
Processing conditions for test specimens																	
C Injection molding melt temperature	-	°C	ISO 294	280	280	280	280	290	290	300	300	280	290	280	280	280	290
C Injection molding mold temperature	-	°C	ISO 294	80	80	80	80	80	80	80	80	80	80	80	80	80	80
C Injection molding flow front velocity	-	mm/s	ISO 294	200	200	200	200	200	200	200	200	200	200	200	200	200	200

All values are typical, not specified values. For more information, see Disclaimer page 28.

Apec®				Higher-viscosity grades		Easy-flowing grades						
Properties	**Test conditions**	**Units**	**Standards**	**UV-stabilized**		**Easy release**			**UV-stabilized, easy release**			
				1703	**1803**	**A.1695**	**A.1795**	**A.1895**	**1697**	**1797**	**A.1897**	**2097**
Rheological properties												
C Melt volume-flow rate (MVR)	330 °C; 2.16 kg	cm³/10 min	ISO 1133	17	10	45	30	18	45	30	18	8
Melt mass-flow rate (MFR)	330 °C; 2.16 kg	g/10 min	ISO 1133	17	10	46	31	19	46	31	19	8
C Molding shrinkage, parallel	60x60x2 mm	%	ISO 294-4	0.8	0.85	0.75	0.8	0.85	0.75	0.8	0.85	0.9
C Molding shrinkage, transverse	60x60x2 mm	%	ISO 294-4	0.8	0.85	0.75	0.8	0.85	0.75	0.8	0.85	0.9
Mechanical properties (23 °C/50 % r. h.)												
C Tensile modulus	1 mm/min	MPa	ISO 527-1,-2	2400	2400	2400	2400	2450	2400	2400	2450	2450
C Yield stress	50 mm/min	MPa	ISO 527-1,-2	70	72	68	71	74	68	71	74	76
C Yield strain	50 mm/min	%	ISO 527-1,-2	6.8	6.8	6.2	6.6	6.6	6.2	6.6	6.6	6.9
C Nominal tensile strain at break	50 mm/min	%	ISO 527-1,-2	> 50	> 50	> 50	> 50	> 50	>50	>50	> 50	> 50
C Charpy impact strength	23 °C	kJ/m²	ISO 179-1eU	N	N	N	N	N	N	N	N	N
C Charpy impact strength	-30 °C	kJ/m²	ISO 179-1eU	N	N	N	N	N	N	N	N	N
C Charpy notched impact strength	23 °C	kJ/m²	ISO 179-1eA	9.0	8.0	10	9.0	8.0	10	9.0	8.0	6
C Charpy notched impact strength	-30 °C	kJ/m²	ISO 179-1eA	9.0	8.0	10	9.0	8.0	10	9.0	8.0	6
Flexural modulus	2 mm/min	MPa	ISO 178	2400	2400	2400	2400	2450	2400	2400	2450	2450
Flexural strength	2 mm/min	MPa	ISO 178	105	108	100	105	108	100	105	108	110
Ball indentation hardness	-	N/mm²	ISO 2039-1	120	121	120	124	127	120	124	127	130
Thermal properties												
C Deflection temperature under load, Af	1.80 MPa	°C	ISO 75-1,-2	149	159	138	148	158	137	147	157	172
C Deflection temperature under load, Bf	0.45 MPa	°C	ISO 75-1,-2	161	174	150	161	173	149	160	172	191
Vicat softening temperature	50 N; 120 °C/h	°C	ISO 306	171	184	158	173	183	157	172	182	202
Relative temperature index (tensile strength)	1.5 mm; 3.0 mm	°C	UL 746B	140	150	140	140	150	140	140	150	150
Relative temperature index (tensile impact strength)	1.5 mm; 3.0 mm	°C	UL 746B	130	130	130	130	130	130	130	130	130
Relative temperature index (electric strength)	1.5 mm; 3.0 mm	°C	UL 746B	140	150	140	140	150	140	140	150	150
C Coefficient of linear thermal expansion, parallel	23 to 55 °C	10^{-4}/K	ISO 11359-1,-2	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
C Coefficient of linear thermal expansion, transverse	23 to 55 °C	10^{-4}/K	ISO 11359-1,-2	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
C Burning behavior UL 94 (1.5 mm)	1.5 mm	Class	UL 94	HB	HB	HB	HB	HB	HB	HB	HB	HB
C Burning behavior UL 94	3.0 mm	Class	UL 94	HB	HB		HB	HB	HB	HB	HB	HB
C Oxygen index	Method A	%	ISO 4589-2	25	25	26	26	26	26	26	26	25
Electrical properties (23 °C/50 % r. h.)												
C Relative permittivity	100 Hz	-	IEC 60250	3	2.9	3	3	2.9	3	3	2.9	2.9
C Relative permittivity	1 MHz	-	IEC 60250	2.9	2.8	2.9	2.9	2.8	2.9	2.9	2.8	2.8
C Dissipation factor	100 Hz	10^{-4}	IEC 60250	10	10	10	10	10	10	10	10	10
C Dissipation factor	1 MHz	10^{-4}	IEC 60250	80	80	90	90	80	90	90	90	90
C Volume resistivity	-	Ohm·m	IEC 60093	1E15	1E15	1E15	1E15	1E15	1E15	1E15	1E15	1E15
C Surface resistivity	-	Ohm	IEC 60093	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16	1E16
C Electric strength	1 mm	kV/mm	IEC 60243-1	35	35	35	35	35	35	35	35	35
C Comparative tracking index CTI	Solution A	Rating	IEC 60112	250	450	250	250	250	250	250	250	600
Comparative tracking index CTI M	Solution B	Rating	IEC 60112	125	100	125	125	100	125	125	100	100
Other properties (23 °C)												
C Water absorption (saturation value)	In water at 23 °C	%	ISO 62	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
C Water absorption (equilibrium value)	23 °C; 50 % r.F.	%	ISO 62	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
C Density	-	kg/m³	ISO 1183-1	1170	1150	1180	1170	1150	1180	1170	1150	1130
Material specific properties												
Refractive index		-	ISO 489	1.578	1.573	1.578	1.576	1.573	1.578	1.576	1.573	1.566
Light transmittance (blue tinted material)	1 mm	%	ISO 13468-2	89	89	89	89	89	89	89	89	89
Processing conditions for test specimen												
C Injection molding melt temperature	-	°C	ISO 294	330	330	330	330	330	330	330	330	330
C Injection molding mold temperature	-	°C	ISO 294	100	100	100	100	100	100	10	100	100
C Injection molding flow front velocity	-	mm/s	ISO 294	200	200	200	200	200	200	200	200	200

All values are typical, not specified values. For more information, see Disclaimer page 28.

Bayer MaterialScience

Bayer MaterialScience AG
Business Unit Polycarbonates
D-51368 Leverkusen
Germany
Web: www.plastics.bayer.com
email: plastics@bayer.com

Edition: 2014-08 . Order-No.: MS00060960 . Printed in Germany